SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

UNCLASSIFIED

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY AD-A216 416	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR-89-1785
6a. NAME OF PERFORMING ORGANIZATION Boston University Center for Adaptive Systems	6b. OFFICE SYMBOL (If applicable)
7a. NAME OF MONITORING ORGANIZATION AFOSR/NL
6c. ADDRESS (City, State, and ZIP Code) 111 Cummington St. Boston, MA 02215	7b. ADDRESS (City, State, and ZIP Code) Bldg 410 Bolling AFB, DC 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR	8b. OFFICE SYMBOL (If applicable) NL
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Life Sciences Directorate Bolling AFB, DC 20332	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2313; TASK NO A5; WORK UNIT ACCESSION NO.

DTIC ELECTE JAN 04 1990 S D

11. TITLE (Include Security Classification)
Visual Perception of Structure from Motion

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Annual Technical	FROM 11/1/88 TO 10/31/89	11/20/89	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The research performed by James Todd during the past year of AFOSR support has examined the ability of human observers to perceive various aspects of a moving object's 3D structure from minimal apparent motion sequences. This research has provided a strong body of evidence that the perceptual analysis of 3D structure from motion is apparently restricted to first order temporal relations. That is to say, when all other factors are optimized, perceptual performance does not improve as the number of discrete frames in an apparent motion sequence is increased beyond two. This research has been accompanied, moreover, by a theoretical analysis of the particular properties of 3D structure that can be computed from first order temporal relations. The analysis makes specific predictions about which tasks can or cannot be performed accurately by human observers, and these predictions are in strong agreement with the psychophysical data.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	
22a. NAME OF RESPONSIBLE INDIVIDUAL JOHN F TANGNEY	22b. TELEPHONE (Include Area Code) (202) 767-5021
	22c. OFFICE SYMBOL NL

DD Form 1473, JUN 86 — Previous editions are obsolete. — SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED

Interim Scientific Report

Contract AFOSR-89-0016

Visual Perception of Structure from Motion

November 1, 1988 - October 31, 1989

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My research during the past year has been primarily concerned with the fundamental mechanisms of 3D form perception, and has been specifically motivated by recent theoretical advances in neural and computational modelling. My basic strategy has been to identify the key assumptions of various competing models, and to empirically examine the relative psychological validity of these assumptions using appropriate psychophysical procedures.

Much of this research has been specifically directed at the visual perception of structure from motion. During the past decade, there have been numerous algorithms proposed in the literature for computing an object's 3D form from a sequence of projected images taken from different perspectives. One of the primary results of these analyses is that a minimum of three distinct images in an apparent motion sequence is required in order to obtain an unambiguous interpretation of an object's 3D form. In an effort to test the psychological validity of this conclusion, I have performed numerous experiments, using a wide variety of stimuli and response tasks. The results indicate that different aspects of an object's 3D form are judged with varying degrees of accuracy. Of primary theoretical importance, however, is that none of these tasks are significantly influenced by varying the number of distinct images in an apparent motion sequence if other factors are carefully controlled. I am currently developing a modified computational analysis for approximating various aspects of 3D structure that I believe can account for all of my psychophysical findings.

One fundamental issue that has become a central focus of my research during the past several years concerns the specific nature of an observer's knowledge about objects depicted in visual images. In many theoretical analyses of 3D form perception, it is often taken for granted that an object's structure is perceptually represented as a point-by-point mapping of metric depth or orientation relative to the observer (e.g., the 2 1/2D sketch). My results have not always been supportive of this view. When observers are asked to make judgments that require knowledge of metric structure, they are often surprisingly inaccurate and unreliable, whereas performance is often significantly improved for other types of judgments involving nonmetric structure. In order to account for the wide variation of performance on these tasks, I have adopted a working hypothesis that visual knowledge may be perceptually represented at several different levels of abstraction, including metric representations, ordinal representations, and nominal representations. My plan for the coming year is to compare and contrast the perceptual analyses of these different levels of structure for many different types of moving displays over a wide range of conditions, and to discover the specific sources of optical structure from which they are determined.

I am also beginning to investigate the lower order processes of 2D motion detection, on which the perception of 3D structure from motion must ultimately be based. I am particularly interested in the temporal integration of motion signals over multiple frames of an apparent motion sequence. The initial results of this research, which were reported at the 1989 meeting of the Psychonomic Society, have indicated that temporal integration may occur over multiple time scales. I am currently attempting to elaborate these findings in greater detail, and to develop a neural network analysis to account for the overall pattern of results.

Published Manuscripts and Abstracts

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Todd, J.T., & Reichel, F.D. (1990). The visual perception of smoothly curved surfaces from double projected contour patterns. Journal of Experimental Psychology: Human Perception and Performance, in press.

Todd, J.T. (1989). The visual perception of 3-dimensional structure from minimal apparent motion sequences. Perception & Psychophysics, in preparation.

Invited Conferences and Colloquia

Todd, J.T. Ordinal structure from shading. Conference on Vision and Shape from Shading. Toronto, Canada, September, 1988.

Todd, J.T. Perception of smoothly curved surfaces. Columbia University, September, 1988.

Todd, J.T. Visual perception of structure from motion. Boston University, November, 1988.

Todd, J.T. Minimal conditions for the perception of structure from motion. Meeting of the Psychonomic Society, Chicago, Illinois, November, 1988.

Todd, J.T. Perception of smoothly curved surfaces. Massachusetts Institute of Technology, December, 1988.

Todd, J.T. Perception of 3D structure from motion. Conference on Vision and Three-Dimensional Representation. Minneapolis, Minnesota, May, 1989.

Todd, J.T. Discriminability of 3D structures in kinetic depth displays. Fifth International Conference on Event Perception and Action, Oxford, Ohio, July, 1989.

Todd, J.T. Visual representation of surfaces. Conference on Imaging in Medicine and Biology: Current Issues and Prospects. Philadelphia, Pennsylvania, September, 1989.

Todd, J.T. Visual perception of 3-Dimensional Form. Conference on Domains of Mental Functioning: Attempts at a Synthesis. Bielefeld, Germany, December, 1989.

Todd, J.T. The short-range limit increases for multiple frame apparent motion sequences. Meeting of the Psychonomic Society, Atlanta, Georgia, November, 1989.